

  
SECONDARY ORIENTATION EFFECTS IN A SINGLE CRYSTAL SUPERALLOY  
UNDER MECHANICAL AND THERMAL LOADS

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The nickel-base single crystal superalloy PWA 1480 is a candidate blading material for the advanced turbopump development (ATD) program of the space shuttle main engine (SSME). In advanced liquid propellant rocket engines such as the SSME, the turbine blades are subjected to severe thermal gradients, both along the span and through the thickness during startup and shutdown cycles. In addition, the blades are subjected to centrifugal (arising from the very large rotational speeds) and vibratory loads. In order to improve thermal fatigue resistance of the blades, the single crystal superalloy PWA 1480 is grown along the low modulus [001] crystal orientation by a directional solidification process. Unless a seed crystal is used during the solidification process, the secondary crystal orientation [010] tends to be randomly oriented with respect to the geometry of the turbine blade (ref. 1). Since cubic single crystal materials such as PWA 1480 exhibit anisotropic elastic behavior (ref. 2), the stresses developed within the single crystal superalloy due to mechanical and thermal loads are likely to be affected by the exact orientation of the secondary crystallographic direction with respect to the geometry of the turbine blade.

The effects of secondary crystal orientation on the elastic response of single crystal PWA 1480 superalloy were investigated by using a square plate (25.4-mm side) with a thickness of 3.2 mm. This was accomplished by a parametric study in which the secondary crystallographic orientation was offset with respect to the geometric axes of the square plate from 0° to 90° in increments of 10°. The primary orientation of the square plate was assumed to be along the [001] crystallographic direction. The square plate was subjected to mechanical, thermal, and combined thermal and mechanical loads; the elastic stresses developed within the single crystal PWA 1480 plate were computed with elastic finite-element stress analysis for each combination of loading condition and secondary orientation angle.

Temperature-dependent elastic constants and the thermal coefficient of expansion for single crystal PWA 1480 were determined by the engineering division of Pratt & Whitney, United Technologies Corporation under the NASA Lewis Research Center Contract NAS3-23939 (ref. 3). The elastic stiffness matrices for different secondary orientation angles were computed by using the simplified method of Lieberman and Zirinsky (ref. 4). The commercially available MARC code was used to conduct the elastic stress analyses (ref. 5). The finite-element model of the square plate consisted of 500 8-noded,

isoparametric elements. The elastic stresses developed within a few selected elements in the finite-element mesh under mechanical, thermal, and combined thermal and mechanical loads, and the variation of these elastic stresses with the secondary orientation angle are presented.

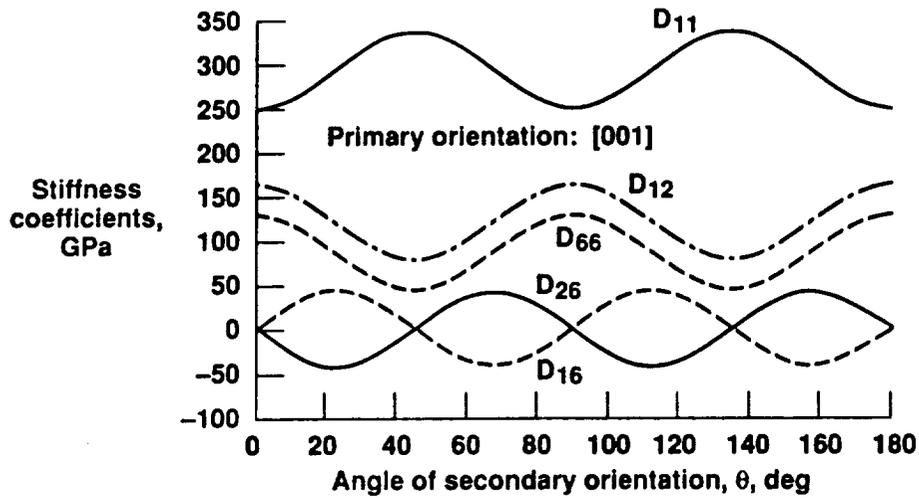
Results of the parametric study indicated that the variations in the stress components with the secondary orientation angle were dependent on the type of loading (mechanical, thermal, or combined) imposed on the square plate. It was also found that, for a case involving thermal gradient through the thickness of the square plate, the secondary orientation angle of  $0^\circ$  minimizes thermal stresses whereas the secondary orientation angle of  $45^\circ$  maximizes the thermal stresses.

#### REFERENCES

1. Duhl, D.N., "Single Crystal Superalloys", Superalloys, Supercomposites and Superceramics, J.K. Tien and T. Caulfield, eds., Academic Press, Inc., 1989, pp. 149-155.
2. Nye, J.F., "Physical Properties of Crystals, Their Representation by Tensors and Matrices", Clarendon Press, Oxford, 1957, pp. 131-149.
3. Swanson, G.A., Linsak, I., Nissley, D.M., Norris, P.P., Meyer, T.G., and Walker, K.P., "Life Prediction and Constitutive Models for Hot Section Anisotropic Materials Program, Second Annual Status Report", NASA CR-179594, 1987.
4. Lieberman, D.S., and Zirinsky, S., "A Simplified Calculation for the Elastic Constants of Arbitrarily Oriented Single Crystals", Acta Cryst., 9, 1956, pp. 431-436.
5. MARC General Purpose Finite Element Analysis Program, Vol. A: User Information Manual; Vol. B: Marc Element Library; Vol. F: Theoretical Manual. MARC Analysis Corporation, Palo Alto, CA, 1988.

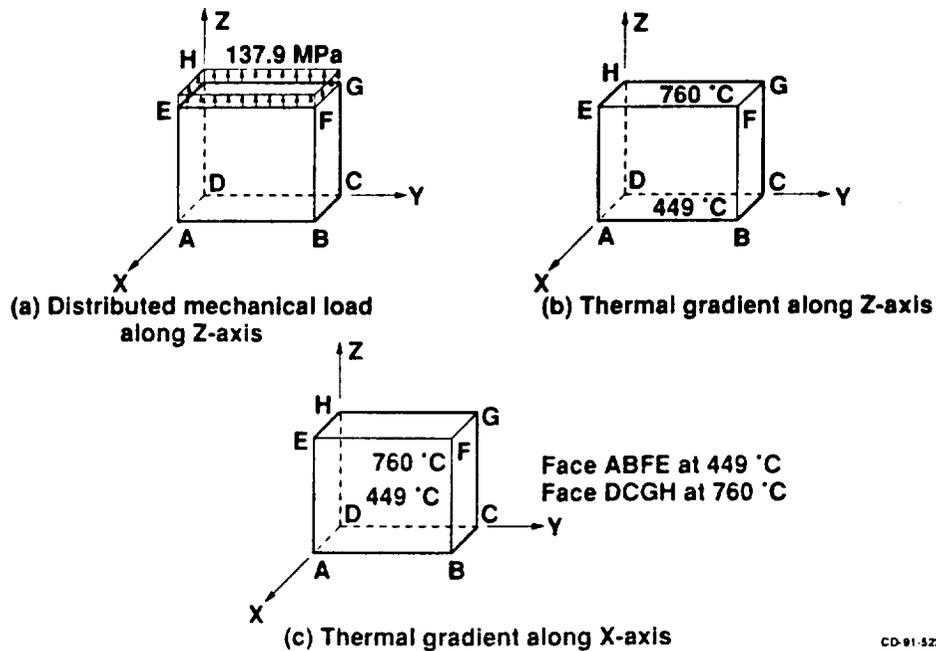
## Elastic Stiffness Coefficients of PWA 1480 SC at 38 °C

( $C_{11} = 250$  GPa;  $C_{12} = 163$  GPa;  $C_{44} = 129$  GPa)



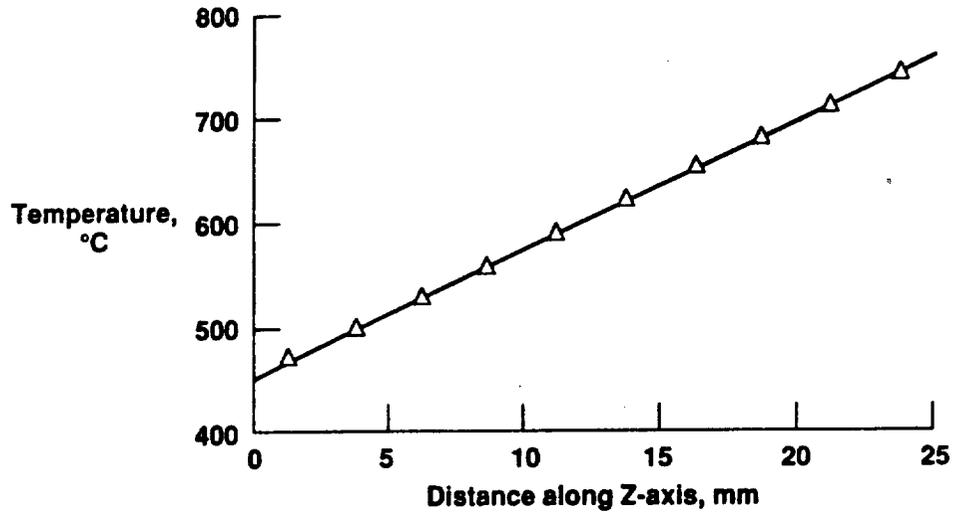
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## Mechanical and Thermal Loads Imposed on the Single Crystal PWA 1480 Square Plate



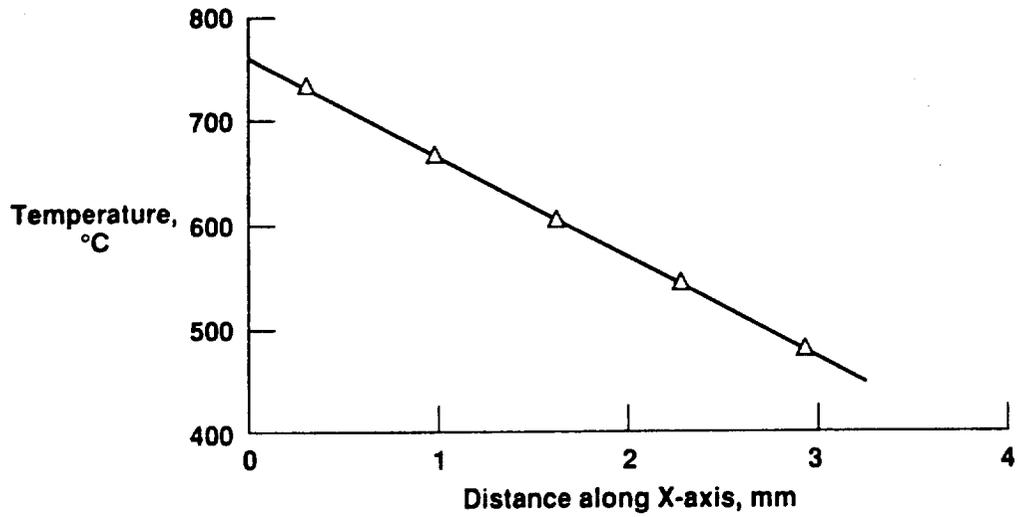
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### Imposed Thermal Gradient Along Z-Axis



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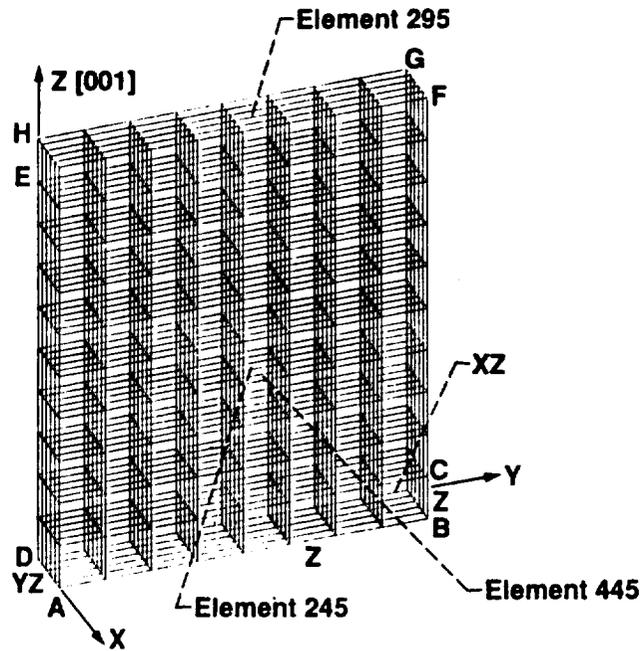
### Imposed Thermal Gradient Along X-Axis



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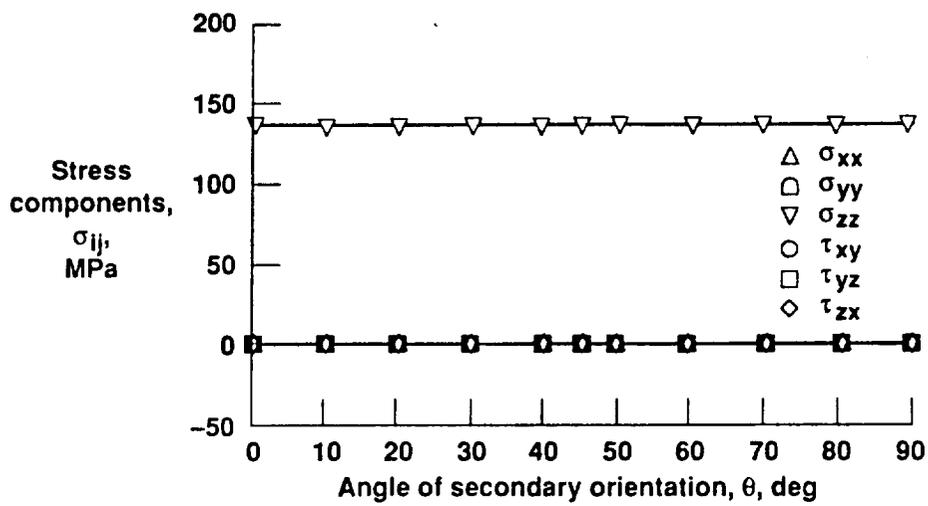
## Finite-Element Mesh

### 500 8-Noded Isoparametric Elements



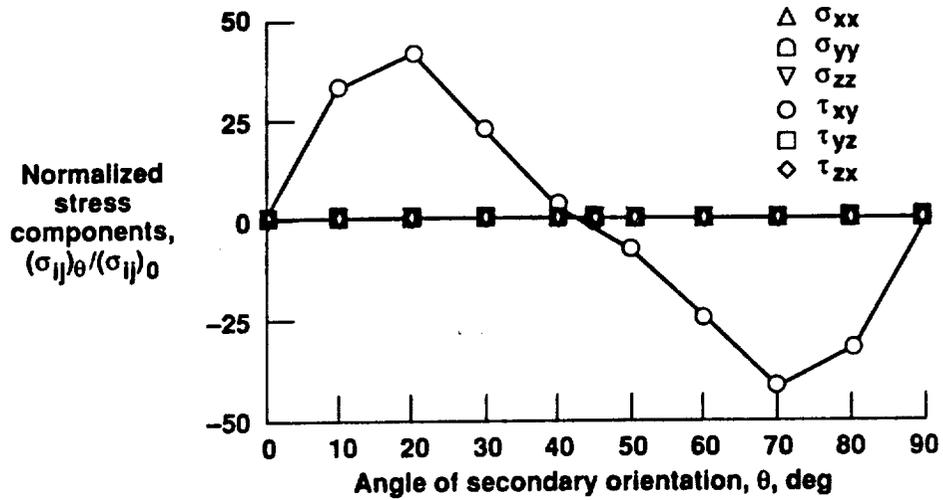
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## Mechanical Loading: Element 245



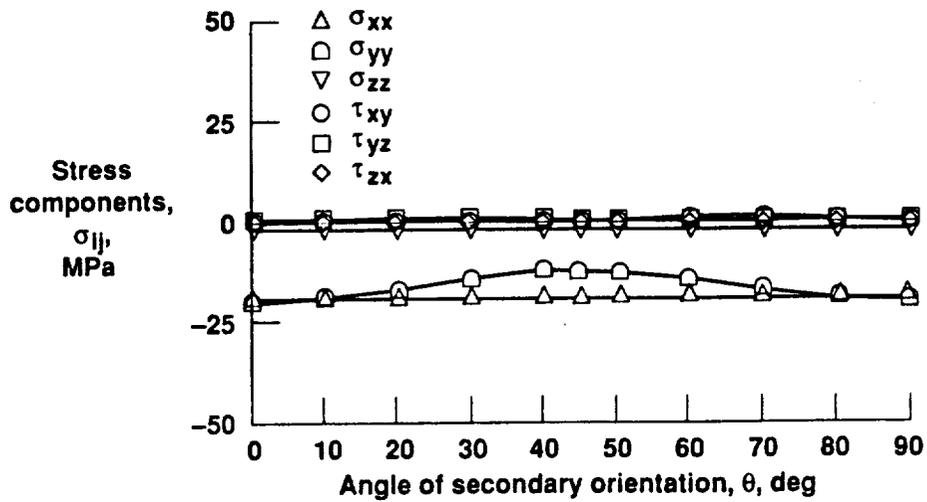
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### Mechanical Loading: Element 245



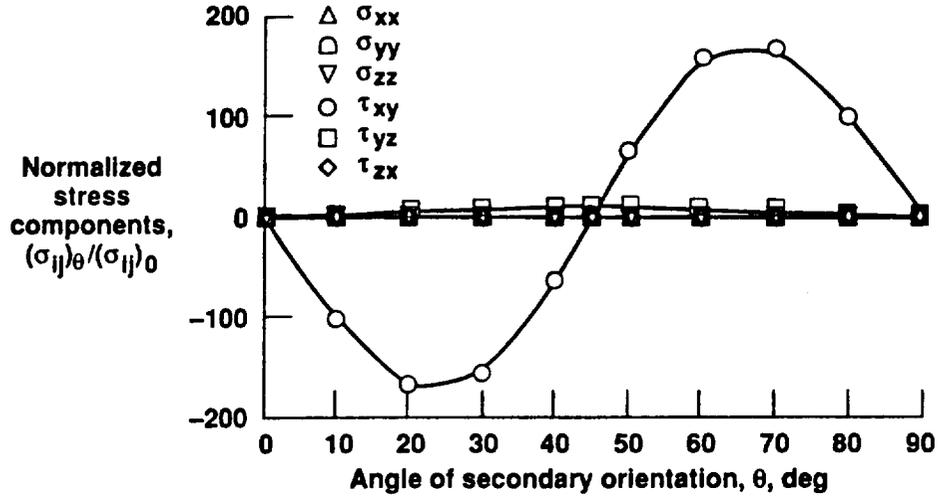
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### Thermal Loading in Z-Direction: Element 295



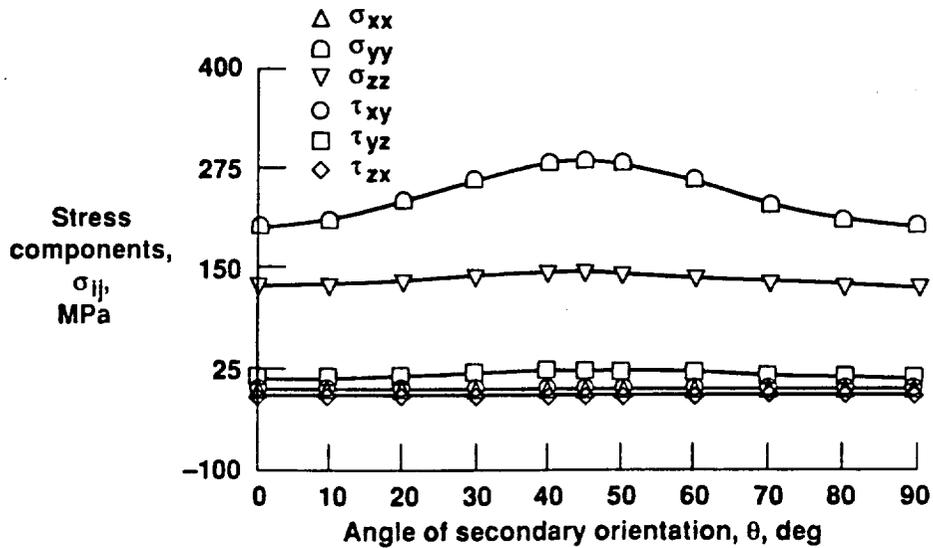
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### Thermal Loading in Z-Direction: Element 295



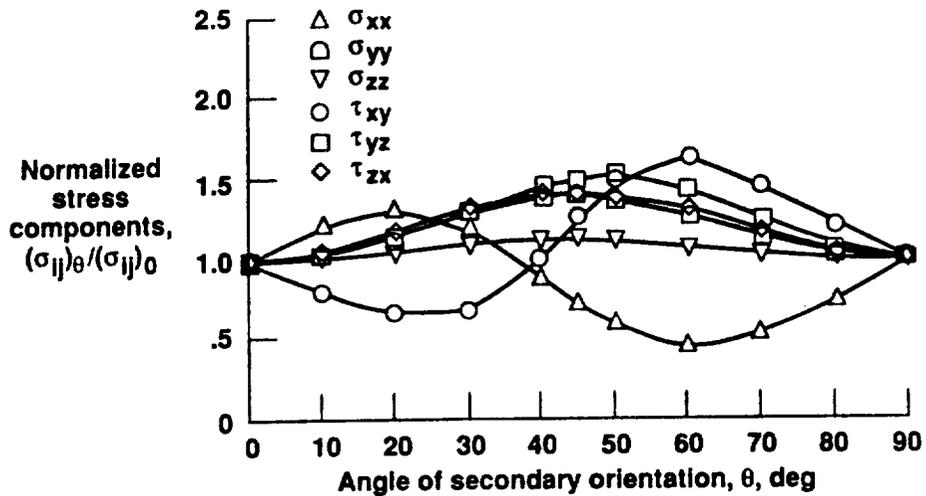
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### Thermal Loading in X-Direction: Element 445



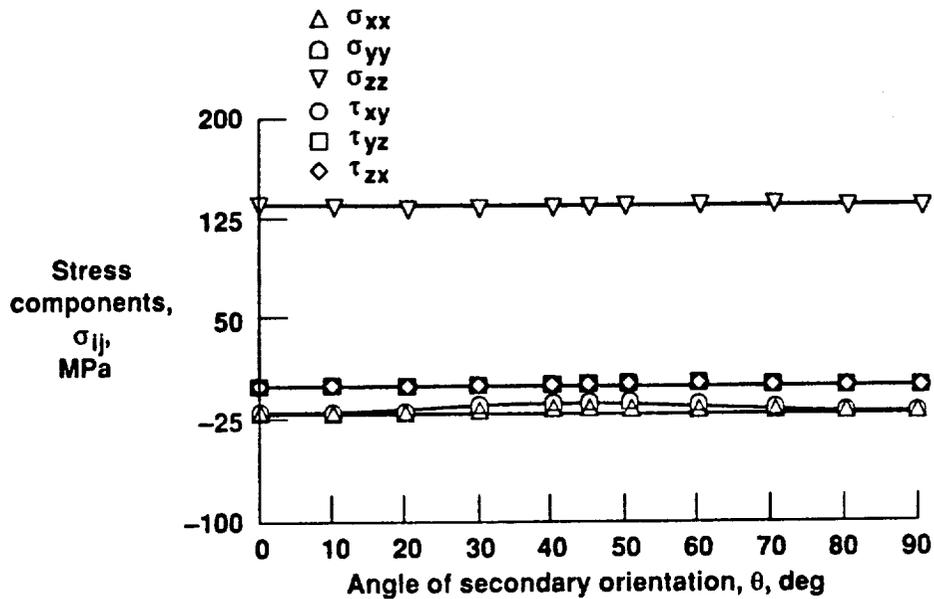
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### Thermal Loading in X-Direction: Element 445



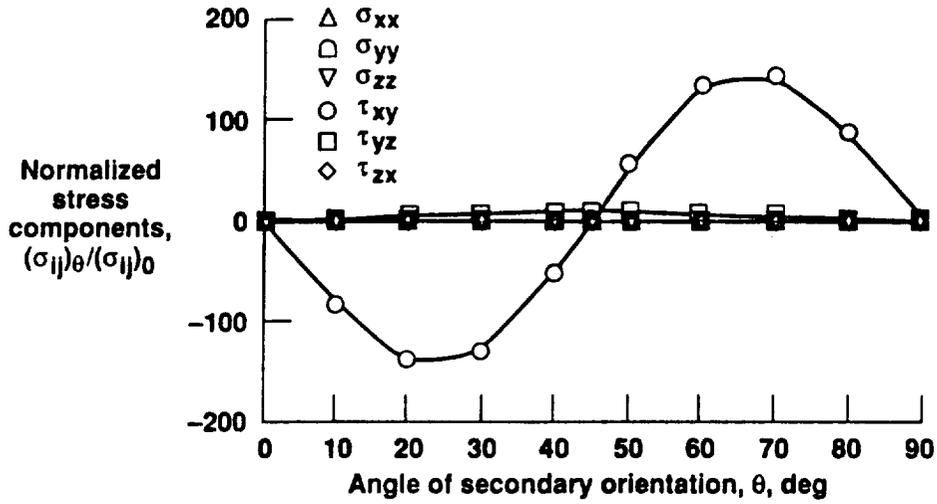
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### Thermal and Mechanical Loading in Z-Direction: Element 295



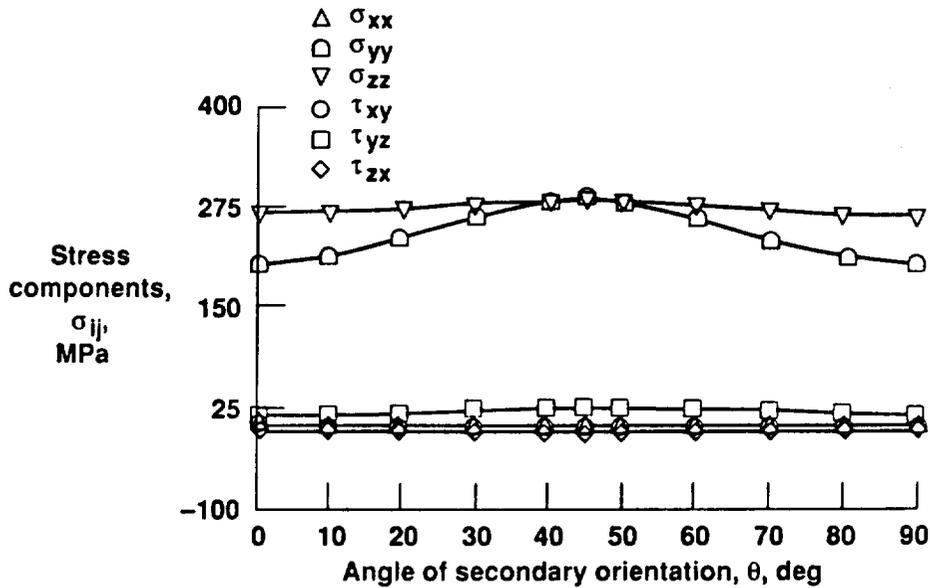
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### Thermal and Mechanical Loading in Z-Direction: Element 295



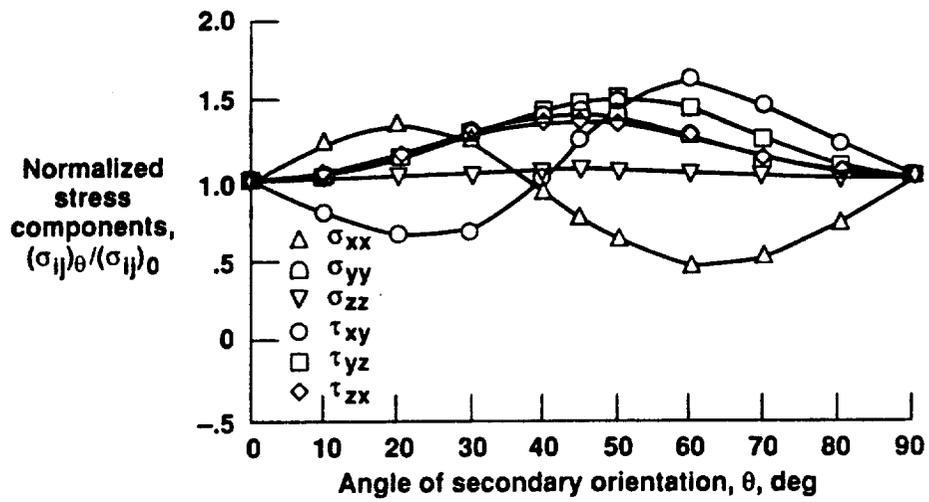
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### Combined Thermal (X-Direction) and Mechanical (Z-Direction) Loading: Element 445



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### Combined Thermal (X-Direction) and Mechanical (Z-Direction) Loading: Element 445



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